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The MSY concept in a multi-objective fisheries environment – lessons from the North Sea

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Abstract

One of the most important goals in current fisheries management is to maintain or restore stocks above levels that can produce the maximum sustainable yield (MSY). However, it may not be feasible to achieve MSY simultaneously for multiple species because of trade-offs that result from interactions between species, mixed fisheries and the multiple objectives of stakeholders. The premise in this study is that MSY is a concept that needs adaptation, not wholesale replacement. The approach chosen to identify trade-offs and stakeholder preferences involved a process of consulting and discussing options with stakeholders as well as scenario modelling with bio-economic and multi-species models. It is difficult to intuitively anticipate the consequences of complex trade-offs and it is also complicated to address them from a political point of view. However, scenario modelling showed that the current approach of treating each stock separately and ignoring trade-offs may result in unacceptable ecosystem, economic or social effects in North Sea fisheries. Setting F_{MSY} as a management target without any flexibility for compromises may lead to disappointment for some of the stakeholders. To treat F_{MSY} no longer as a point estimate but rather as a “Pretty Good Yield” within sustainable ranges was seen as a promising way forward to avoid unacceptable outcomes when trying to fish all stocks simultaneously at F_{MSY}. This study gives insights on how inclusive governance can help to reach consensus in difficult political processes, and how science can be used to make informed decisions inside a multi-dimensional trade-off space.

Keywords: MSY, MEY, bio-economic, mixed fisheries, multi species, North Sea

1. Introduction

The use of the Maximum Sustainable Yield (MSY) concept as a fisheries management objective aims to get the most from a resource over a long time period (Schaefer 1954, Beverton and Holt 1957). The MSY definition in the European Common Fisheries Policy (CFP, EU 2013) is *"the highest theoretical equilibrium yield that can be continuously taken on average from a stock under existing average environmental conditions without significantly affecting the reproduction process"*. The applicability of this definition in practice is likely to be limited to a single species with fairly stable dynamics. There are well-documented problems with the definition and performance of MSY targets in fisheries, even for a single-species if there are natural deviations from theoretical equilibrium assumptions (Mace 2001). Where there are multiple interacting species and/or multiple objectives it becomes even more difficult to simultaneously evaluate the trade-offs that inevitably occur and establish any overall optimised outcome. For management involving complex biological interactions and diverging objectives, the MSY concept may be inherently inappropriate (Matsuda and Abrams 2004, 2006; Walters et al. 2005; Mackinson et al. 2009). Larkin (1977) recognized that single species MSY cannot be achieved for all species inside an ecosystem simultaneously when biological interactions (such as predator-prey relationships) are considered. Likewise, technical interactions in mixed fisheries create major difficulties in obtaining maximum sustainable yields for several species simultaneously when species are caught together (Kraak et al. 2013). The implementation of a landing obligation (EU 2013; Article 15) renders the issue even more complex, because it is generally difficult to exhaust the individually advised quotas for all species at the same time in mixed fisheries and the most limiting quota becomes limiting for the entire fishery (Batsleer et al. 2013, Ulrich et al. 2011), the so-called "choke-species" effect.

Article 2 of the CFP (EU 2013) calls for long-term sustainability of marine resources as well as economic, social and employment benefits. The CFP also requires a precautionary and ecosystem based approach to fisheries to minimise the negative impacts of fishing activities on the marine ecosystem. Therefore, the CFP sets out a regime in which the economic and social constraints must be respected and precaution pre-empts maximisation, leading to further potential conflicts between objectives.

There has been a long search for alternatives to MSY that would allow for more effective fisheries management. The Maximum Economic Yield (MEY) concept includes the cost of fishing and the income gained, and aims to maximise profit. In single species fisheries, the fishing mortality at which MEY occurs is usually at a lower fishing effort than that required for MSY (Clark 1990, Hersoug 1996, Grafton et al. 2007), and typically corresponds to a limited number of fishing vessels each with large profits. The shift to an economic objective still aims at maximisation of some defined and relatively stable equilibrium value (Gordon 1954, Grafton et al. 2007). Subsequent to the development of MEY, scientists have noted the importance of addressing wider social concerns, reflecting a desire to ensure more equitable distribution of economic benefits (Hilborn 2007, Macinko and Bromley 2002). The "Pretty Good Yield" concept outlined by Hilborn (2010) is an example of an attempt to compromise between ecological, economic and social goals, while retaining some technical rigour.

Multiple objectives are difficult to address from a political and scientific perspective. Often decisions must be made based on uncertain scientific results, and compromises between different stakeholders must be found. Expert and preference elicitation is a way to integrate the subjective opinion of different stakeholders and experts to provide decision support in conservation management (Mardle et al. 2004, Smith et al. 2007, Martin et al. 2011). If decisionsare to be fully accepted then opinions of stakeholders should be included in the process to help ensure legitimacy of the management (Smith et al. 1999, Mardle et al. 2004, Röckmann et al. 2012).

A large pan-European research project (MYFISH, www.myfishproject.eu) was launched in 2012, to investigate the MSY concept in depth by gathering the opinion of different stakeholders on issues and trade-offs linked to various options. The project aimed to get a better understanding of the applicability and the impact of alternative MSY definitions. This study describes the approach taken in MYFISH to identify and evaluate alternative decision frameworks that could offer more relevant management guidance than MSY (in its original definition) when applied to North Sea fisheries. The focus was on the European legislation because all countries with fishing rights in the North Sea are EU members, apart from Norway. The study proceeds with the premise that MSY is a positive concept that needs adaptation, not wholesale replacement. Particularly the issues of (i) trade-offs in objectives, (ii) the need to evaluate the whole rather than the particular, and (iii) considering acceptable ranges of uncertain outcomes - not just the optimum - were addressed by combining aspects of expert and preference elicitation with multi-species and mixed fisheries scenario modelling. Problems that can be anticipated when implementing the MSY policy in the North Sea mixed fisheries were highlighted.

2. Materials and Methods

The task of implementing MSY-related principles in a multi-species environment with diverging objectives among different stakeholder groups is complex. The approach, directed at the specific case of the North Sea fisheries, involved a process of consulting and discussing options with stakeholders in four steps:

1. A problem framing workshop to identify MSY objectives and constraints and determine a ranking of options
2. Two management reflection workshops to discuss the rankings and refine options
3. Scenario modelling of preferred options to prepare Decision Support Tables
4. A decision support workshop for stakeholder feedback and validation, based on modelling of scenarios in which preferred options were implemented.

A specific issue linked to using a stakeholder-elicitation approach is to ensure that relevant stakeholders attend the workshops. Systematic efforts were made throughout the project to inform and invite a broad range of stakeholders. However, attendance at the various workshops remained unequal in terms of number and composition of stakeholder groups (Figure 1), and composition varied between workshops. The workshop records are therefore treated as a ‘snapshot’ of opinions.

[Figure 1 here]

2.1 Problem framing workshop

The problem framing workshop was held in April 2012 and was designed to establish the feasibility of a range of objectives (in terms of yield or other outcomes) which could be maximised, and a range of sustainability indicators that could be used to define constraints. The North Sea problem framing workshop was held as part of a larger scale MSY workshop including industry representatives, NGO representatives, and scientists covering several regions. As a starting point, groups with participants from all European sea regions defined a list of potential objectives and constraints. These lists were the basis for parallel regional groups to determine how to rank the different options. The group addressing problem framing in the North Sea consisted of 12 persons (Figure 1).

The methodology for eliciting stakeholder views used in this workshop combined elements of open group interviews and specialized elicitation tools to record opinions, reflecting both consensus and differences of opinion amongst workshop attendees (Leach et al. 2014). A specially designed Excel-based graphical tool was used to facilitate discussions and the documentation of conclusions. Potential objectives to be maximised were listed, and participants were asked to provide ratings (R) of importance for each option and to document the degree of uncertainty or disagreement in the group (U) on each option. For MSY objectives (What should be maximised?), ratings and uncertainty were required with respect to three aspects: i) Does the necessary information exist? ii) How informative is it in relation to the objective? and iii) Is it likely that management measures will result in meeting the objective? For MSY constraints only the overall importance in the region was rated.

An example set of plots showing distributions of ratings from the graphical tool are shown in Figure 2. The tool was particularly helpful for groups to visualise consensus or disagreement about different aspects of an option and each participant could see that individual opinions were included within the distribution. The Rating and Uncertainty for each option from the various stakeholder groups were combined into a unique utility index using a matrix method (Holt et al. 2014).

[Figure 2 here]

2.2 Management reflection workshops

The results of the problem framing workshop were presented at two subsequent meetings in October 2012 (ICES/MYFISH WKM-TRADE; ICES WKM-TRADE 2012) and in February 2013 (ICES/Nordic Council of Ministers (NCM) Workshop; Rindorf et al. 2013). There were 17 and 38 participants in these two management reflection workshops, respectively (Figure 1). While the problem framing workshop was dominated by scientists, the management reflection workshops included more managers, fishing industry representatives and Non-Governmental Organisations (NGOs). Therefore, they provided a good forum to discuss the findings of the first workshop and to determine whether the rankings are representative for a different group of stakeholders. The workshops were structured with short presentations reflecting the preferred objectives and constraints indicated by the Problem framing workshop followed by plenary discussions. No specific elicitation tool was used in these workshops.

2.3 Scenario modelling of preferred options

The stakeholder opinions on objectives and constraints derived from the workshops were used to identify relevant scenarios to be included in Decision Support Tables (DSTs). In these DSTs stakeholders can use selected indicators to compare management decisions based on likely impacts. Three DSTs were created for the North Sea demersal fisheries, focusing on different issues and types of fisheries in different areas of the North Sea. The best available model was selected for each case and updated to address the topic. Two DSTs focused on the mixed demersal gadoid fishery as a case study (mainly distributed in the central and northern North Sea) and one on the mixed flatfish and brown shrimp fishery in the southern North Sea. For simplicity, it was decided to look at trade-offs resulting from biological interactions separately to those arising from technical interactions in mixed fisheries. A hierarchical organisation of DSTs was used focusing first on biological interactions, then on technical interactions in mixed fisheries and finally on trade-offs taking also into account the sustainable exploitation of by-catch species and the size structure in the ecosystem (technical interactions and Good Environmental Status (GES)). In all three cases, the two generic MSY objectives of maximising total landings in weight and in Euros were analysed. Additional case-specific optimisation scenarios were added, as described below. The scenarios tested cover extreme trade-offs likely to be encountered and should be interpreted as being indicative of the broad scale direction of change. All trade-offs of the various cases and scenarios were visualised using standardised graphical outputs such as icon arrays that have been demonstrated to be more easily understood by non-scientists while conveying a large amount of complex information (Ancker et al. 2006, Spiegelhalter et al. 2011).

MSY accounting for species predator-prey interactions (DST1)

The effect of species interactions on long term yield and sustainability was assessed by producing 100 year forecasts with the stochastic multi-species model SMS (Lewy and Vinther 2004, ICES WGSAM 2012). The model can produce a full stochastic forecast of stock size and catch under the assumption that fish are consumed by other fish according to observed stomach contents from around two hundred thousand stomachs and a diet selection model. The model describes catches of the interacting species cod (*Gadus morhua*), saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), herring (*Clupea harengus*), sprat (*Sprattus sprattus*), Norway pout (*Trisopterus esmarkii*) and sandeel (*Ammodytes spec.*). Cod and saithe are top predators feeding on all other species and, in the case of cod, younger conspecifics. Whiting is a mid-level prey and predator feeding on juvenile cod, haddock and whiting as well as herring, sprat, Norway pout and sandeel of all ages. Haddock feeds on sandeel and Norway pout only. In addition to the two generic MSY scenarios, a third scenario was examined aiming for a yield in tonnes close to the maximum of each species (at least 95% of maximum yield) while assuring that no species are exploited unsustainably (“Pretty Good Yield” scenario). To evaluate the performance of management options, for each species it was determined whether the average spawning stock biomass at equilibrium was above the reference points B_{lim} (below B_{lim} there may be impaired recruitment because of a low spawning stock) and B_{pa} (precautionary reference point taking into account the uncertainty in the assessments to ensure that the stock was above B_{lim} with high probability). In the standard MSY scenarios uncertainty was included and multiple simulations run. Outputs were tested against the criterion that 95% of results had stocks staying above B_{lim} and B_{pa} . For the "Pretty Good Yield" scenario only deterministic simulations and outputs were computationally feasible. B_{lim} and B_{pa} were the officially agreed reference points from ICES (ICES WGNSSK 2013) - or in the case of whiting – from the ICES advice on multi-species considerations for the North Sea (ICES Multi 2013).

MSY accounting for mixed-fisheries technical interactions (DST2)

The multi-species multi-fleet model FISHRENT (Salz et al. 2011, Frost et al. 2013) was used to study how to maximise yield under the assumption that the advised total allowable catches (TAC) are set separately in a single species context but a landing obligation is implemented and fleets have to stop when the first quota is exhausted. The model included 12 North Sea fishing fleets and 10 species including the four gadoids cod, haddock, saithe and whiting as well as Norway pout, sandeel, herring, sprat, plaice (*Pleuronectes platessa*) and sole (*Solea solea*). Given the single species F_{MSY} targets and associated overall total allowable catch (TAC) of each species, the distribution of quotas over the fleets was optimized to reach given objectives. The TAC for each stock was set in the model in accordance with the single species F_{MSY} defined by ICES or in the case of cod the target fishing mortality from the current management plan (ICES WGNSSK 2013, ICES Multi 2013, EU 2008). The relative stability condition between countries, i.e. each country obtains a fixed share of the TAC, was respected and only a redistribution of quotas between fleets inside a country was allowed. The two generic MSY-scenarios were investigated focusing on the four gadoid target species cod, whiting, haddock and saithe. In relation to MEY, a maximisation of the net present value (NPV) of the profit (remuneration discount rate of 3.5% after remuneration of capital and labour) over 25 years was carried out including the dynamics, moving from the present situation to the optimal situation. The three scenarios were contrasted to a fourth "traditional management" scenario based on fixed quota shares where no maximisation and redistribution of quotas between fleets inside a country was allowed. All scenarios were constrained by the assumptions (i) that catches of all species were kept below the single species TACs each year, (ii) that a landings obligation was implemented and all catches were landed and sold, (iii) the maximum TAC change per year was +/- 15%, and (iv) because of technological constraints, the maximum average increase in capacity (number of vessels) was restricted to +4% of the capacity in the previous year. Fish prices and costs were kept constant at the average 2008-2010 level throughout the 25 years simulation period. Prices and costs were extracted from the account statistics of the Scientific, Technical and Economic Committee for Fisheries (STECF 2013).

MSY accounting for technical interactions and Good environmental status (GES) (DST3)

In a third case study the long-term consequences of aiming for different objectives in the flatfish (plaice and sole) and brown shrimp (*Crangon crangon*) fisheries in the Southern North Sea were evaluated. An approach with paired models was chosen. The spatially explicit bio-economic model Simfish (Bartelings et al. 2015) based on FISHRENT (Salz et al. 2011) and the ecosystem model Ecopath with Ecosim (EwE; Christensen and Walters 2004, Christensen et al. 2008) were utilized in parallel. Optimisations were carried out in Simfish and afterwards the optimized fishing effort was transferred to EWE to evaluate the impact on GES related criteria for bycatch species and a large fish indicator (LFI).

Simfish was parameterized for the fisheries targeting sole, plaice and brown shrimps including German, Dutch and UK trawl fleets. In addition to the two generic MSY scenarios, a third MEY scenario investigated the maximisation of the net present value of the fleet profits (discount rate 3.5%) over 40 years. The profit is defined as the revenue minus variable and fixed costs. In a fourth “MEY constrained” scenario the fishing effort was constrained to ensure a sustainable exploitation of bycatch species such as turbot and elasmobranchs (see below). The following assumptions were made during the optimisation: i) to avoid unrealistic variation of effort from year to year the change in effort is limited to +/-5% per year for each fleet and is fixed after 10 years of simulation to reach equilibrium levels of catch, ii) total effort is constrained but the spatial distribution of fleets in the

North Sea is free, iii) the landings obligation is not implemented because there is still uncertainty how it will be applied in the flatfish and shrimp fisheries (the brown shrimp fishery is already exempted) and a fixed proportion of undersized catch is discarded and iv) the fleet capacity is derived from the total effort, dividing the total days-at-sea per fleet by the initial average days at sea per vessel. Fish prices and costs were extracted from the European fisheries economic database (STECF 2013). Costs and prices of plaice were kept constant at the average 2008-2010 values throughout the simulation period but price elasticity was assumed for sole and brown shrimp prices to account for the observed relationship between landed volumes and prices (de Wilde 2003, ICES WKCCM 2013). The dynamics of the fish stocks were simulated with logistic productivity functions for flatfish and a polynomial function for shrimp using data from ICES WGNSSK 2012 and ICES WGCRAN 2012.

Stäbler et al. (2016) parameterized an EwE model of the southern part of the North Sea (ICES areas IVb and IVc). The model represents all parts of the ecosystem including primary producers, zooplankton, benthos, demersal and pelagic fish, rays and sharks, marine mammals and seabirds. The fishery is represented by eleven fleets typical for the southern part of the North Sea (e.g., demersal trawls and seines, beam trawls, shrimp trawlers and static gears). It was tested whether the fishing mortality for turbot (*Scophthalmus maximus*) was kept below the F_{MSY} proxy of 0.34 (ICES WGNSSK 2013). As further indicator species the elasmobranchs thornback ray (*Raja clavata*), spotted ray (*Raja montagui*) and starry ray (*Amblyraja radiata*) were chosen. These species occur regularly in the southern and central part of the North Sea. It was tested whether the optimized effort levels are sufficient to lead to catches in line with the ICES advice for these species (ICES advice 2013; +20% in TAC for thornback and spotted ray; -36% in TAC for starry ray). The ICES advice was taken as proxy for GES because official long-term target reference levels do not yet exist. Next to this a LFI as further potential GES indicator was calculated representing the proportion of demersal fish species with a maximum length above 40 cm. The threshold of 40 cm was also used by Greenstreet et al. (2011) analysing LFIs for the North Sea fish community.

2.4 Decision support workshop

A decision support workshop was held in July 2014 to determine informed preferences of the participants for different scenarios. The joint workshop with the North Sea Advisory Council (NSAC) had 23 participants (Figure 1). Similar to the problem framing workshop, the priorities of stakeholders for different MSY/MEY objectives and their response to constraints were identified. However, this time stakeholders were confronted with modelling results summarized in the DSTs and they were asked to indicate their preferences given the trade-offs emergent in the modelling results. Therefore, this workshop helped to validate the original outcomes of the Problem framing workshop and the DSTs provided the basis for further discussions.

For each of the DSTs the background of the scenarios and a brief description of the modelling approach and its shortcomings were presented. In contrast to the problem framing workshop, the preferences were collected through questionnaires and not via the Excel tool. While group elicitation methods enable sharing of information and offer a sense of equitable treatment with the opportunity for individual voices to be heard and reflected in a transparent manner (Romakkaniemi 2015), equitability in a group setting, although desirable, is not automatic. Some individuals can assert their dominance and be seen to unfairly influence group-based outcomes. Such bias can also arise from a subgroup of individuals who share a particular background and might therefore hold similar views. In such cases their influence on the group opinion might be judged by others to be unsuitably dominating. Concerns on such group interaction effects had been raised during the problem framing workshop. To minimize these concerns, participants (not including scientists) were asked to indicate their preferences individually for each of the scenarios presented in the DSTs (suitability; score 1 = very poor to 5 = very good). They were also asked how certain they were about their rating (uncertainty; score 1= low uncertainty to 4= high uncertainty). Finally, there was opportunity for them to give the main reasons for their ratings (in free text format). The questionnaires were analysed by taking the individual answers, converting them to distributions approximating the discrete scheme of the Excel tool adopted in the problem framing workshop (Fig.

2) and then averaging the samples into single distributions. This was consistent with the methods used in the problem framing workshop and it synthesised all individual views on the suitability of various management scenarios and the uncertainty surrounding those views. In addition, the DSTs were discussed in a plenary meeting and minutes on the main points raised during the discussions were taken.

3. Results

3.1 Problem framing workshop

Responses to MSY /MEY objectives and constraints were ranked according to expected utility values and the outcomes are presented in Table 1 and 2 respectively. These were binned into 5 equally-sized expected utility groups, on an interval [0,4], resulting in the thresholds 0.0-0.8 for the first priority, and so forth. Lower utility index values correspond to preferred options. The top-ranked objective was “Maximise inclusive governance” (Table 1). Other priority objectives were “Maximise yield in value of key commercial species” and “Maximise yield in tonnes of key commercial species”. “Maximise yield of fish/litre of fuel (or CO_2) or similar energy unit” and “Maximising net present value” were ranked as the most preferred MEY related objectives (Table 1). In the top group of objectives “Maximise consumer welfare/happiness” can be also found. While MSY and MEY related objectives can be predicted with models, the maximisation of inclusive governance was interpreted as maximisation of stakeholder involvement during the definition and implementation of an MSY policy. Consumer welfare and happiness were also difficult to define and criteria for happiness and welfare most likely change through time and between social groups.

[Table 1 here]

Good environmental status (GES) related constraints were ranked highest (Table 2). This also included constraints to ensure sustainable mortality rates for non-target species. In general, there was a wide variety of opinions on most constraints and often ratings ranged from very good to very poor. This led to similar expected utilities for many constraints (Table 2). Relative stability and area closures, such as wind parks and Natura 2000 sites, were also seen as important constraints. This should not be seen as an agreement to relative stability or area closures but more as a political constraint because participants felt that it is not possible to change these things in the near future. Socio-economic constraints were generally ranked low. “Profits above a minimum level” was seen as the most important economic constraint. Typical social constraints such as “Maintaining small communities at a specified level” or “Employment above a specified level” were ranked low.

[Table 2 here]

3.2 Management reflection workshops

In general, the participants of the two workshops considered that the aim of fisheries management must be compatible with the stocks being maintained above precautionary limits, e.g. limits below which recruitment of the stock is impaired (ICES WKM-TRADE 2012, Rindorf et al. 2013). Within the area defined as compatible with sustainability, scientists are expected to provide advice on the relevant trade-offs between different yield and ecosystem aspects. However, they should not be responsible for making decisions on the exact trade- off of different objectives in an automated fashion such as through trading a kilo or a euro landed value of one fish species against that of another. Such information may be presented to guide decision makers but should not be considered as legally binding in the decision process. In the second of the two workshops (Rindorf et al. 2013), it was considered that it would not be politically feasible to reach a consensus on decisions where one country would have to loose yield in order for the summed European yield to be maximised. A structure where scientists provide advice on the combination of management targets which were considered sustainable and which would provide yields reasonably close to single species MSY was considered to be a potentially useful route forward. The impression that GES related constraints are most important was also the result of these two workshops. As long as these constraints are fulfilled, science should give options and highlight possible trade-offs as demonstrated in the DSTs.

3.3 Scenario modelling of preferred options (DSTs)

Biological interactions (DST1)

In cases where fish eat other fish, the yield in weight is generally highest when the predatory fish, which otherwise would eat smaller fish, are removed (Gislason 1999). This was also the result in the North Sea case examined here (DST1, Figure 3). Hence, obtaining the maximum weight of landings is achieved by fishing with a higher fishing mortality of the two top predators (cod and saithe). This does not provide a substantially higher yield of the two species, but does require a higher fishing effort on these species leading to lower stock sizes. The higher the fishing mortality on the top predators, the higher the abundance of their prey (i.e. whiting and haddock), which leads to an increased probability of the Norway pout stock being below precautionary limits. To obtain maximum total yield in weight or Euros, a substantially higher fishing mortality than that leading to single species MSY of cod and saithe is required and a cost in the form of a cod stock below precautionary limits and a higher fishing effort is the consequence. In contrast, the “Pretty Good Yield” scenario leading to all stocks being retained above biological limits (above B_{lim}) has a fishing effort on cod which is in between that leading to MSY of cod in a single species environment and that leading to the maximum total landings in the North Sea. Long-term yield of predatory fish is only mildly affected by the differences in fishing mortality and hence appear to be virtually identical between scenarios.

[Figure 3 here]

Technical interactions (DST2)

The comparison between the traditional management scenario (distribution of quotas determined by historic landings shares alone) and the three optimisation scenarios (allowing quotas to be redistributed between fleets inside a country) revealed that at the scale of the entire fishery, MEY gives considerably more profit compared to traditional management (Figure 4). Redistribution is also favoured with respect to MSY-related objectives (yield in weight and yield in Euros), the reasons being that traditional management is constrained by being subject to fixed fleet shares of the quotas based on historical landing shares. This leads to a situation where fleets have to stop fishing under a landing obligation relatively early in the year when the first quota is exhausted. However, management based on maximising yield does not take into account the costs of using excessive effort to maximise catch in weight or value. Only in the MEY scenario is the usage of quotas optimised while minimising fishing effort, leading to lower costs. The reduced effort comes at the cost of reduced employment.

[Figure 4 here]

Technical interactions and GES (DST3)

The DST for the southern North Sea case study shows similar trade-offs (DST3, Figures 5 and 6). The current definition of MSY (maximise yield in weight) is not optimal from an economic and conservation point of view. It leads to a substantialy lower profit compared to the other scenarios and risks the unsustainable exploitation of by-catch species. Regarding target species, neither plaice nor sole were predicted to be below B_{pa} in any scenario. It could be shown that economic efficiency and ecosystem sustainability are not mutually exclusive. Aiming for MEY leads to a relatively low fishing effort and therefore to a relatively low by-catch and because of lower fishing mortalities to a better size structure in the ecosystem. The loss in profit caused by the protection of by-catch species

(MEY constrained scenario) was only marginal. However, economic optimization and the protection of by-catch species were achieved with much lower catch and at a high social cost (low employment).

[Figure 5 here]

[Figure 6 here]

3.4 Decision support workshop

Eleven participants (three NGOs, six fishing industry representatives, two policy representatives) filled out the questionnaire for the first DST on multi-species trade-offs (see Figure 3). The scenario “Pretty Good Yield” was evaluated to be most suitable (Figure 7). Arguments from stakeholders at the workshop included that it allows more fishermen to continue fishing because yield is distributed more evenly over the different species. It also leaves room for negotiation because there are no hardwired maximisation objectives. Criticism included the fact that it is not quite clear how such a concept could work out under the current legislation. To maximise yield in weight or Euros was rated considerably less suitable (Figure 7) although it was recognized by workshop participants that these MSY objectives are closer to the current political reality. In the discussion after the presentation of DST1, stakeholders pointed towards the high uncertainty of results, e.g. trends in recruitment success and the complex simulation of biological multi-species interactions. Discussions also picked up the difficulty to reach consensus between member states when trade-offs because of predator-prey interactions become obvious. Each EU member state has different fisheries and therefore different priorities on which species’ yield should be maximised (i.e. the yield from the predator or the prey?).

The questionnaire for DST2 on technical interactions in the mixed roundfish fishery (Figure 4) was filled in completely by seven respondents (three NGOs; three fishing industry representatives, one policy). Another three respondents (fishing industry representatives) evaluated only part of the scenarios. Including all responses, the results show that the scenario “MEY maximise net present value” was deemed most suitable (Figure 7). The explanations for the relatively high rating include the high income. The loss in employment was the main argument against this objective. Traditional management and MSY based on weight were least preferred. The large fleet and low income speak against these scenarios. The “Maximise yield in Euros” scenario was rated in between the MEY and the other two scenarios. The focus of the discussions during plenary was on the appropriateness of the assumption on constant prices and costs. It was also discussed how to deal with the situation in models that fleets continue fishing despite making a loss for a number of years. This situation occurs in reality and was explained by fishing industry representatives with a reluctance of fishermen to close family companies and to lose status.

Regarding the third DST (Figure 5), the appropriateness of limiting fisheries because of sustainability constraints for by-catch species like turbot was discussed at the workshop next to discussions on pros and cons to choose MEY instead of MSY as management targets especially in relation to social constraints. The questionnaire for the third DST was filled in completely by six respondents (three NGOs; two fishing industry representatives; one policy). Another two respondents (fishing industry representatives) evaluated only part of the scenarios. Including all responses, the results show that the ”MEY constrained” scenario received highest scores (Figure 7). Arguments for this scenario included no overfishing of turbot and elasmobranchs. The main argument against was the negative effect on employment (despite high income).

[Figure 7 here]

4. Discussion

4.1 Main conclusions

Multiple trade-offs occur when implementing the MSY concept in the North Sea because of biological interactions, technical interactions, and social constraints. Trade-offs related to biological interactions were identified by managers in the management reflection workshops as being an issue of high potential conflict, with single species management still preferred. The current definition of

MSY to maximise the yield in weight from a stock or community leads to a loss in profit and the relatively high fishing effort needed to fish out the associated quotas increases the potential for conflict with environmental constraints. MEY seems to be an appropriate concept to cover wider objectives, however, employment and the activity of fishing fleets might suffer when aiming for MEY instead of MSY. Although addressing trade-offs is complicated from a political point of view, the motivation to address them may change if the current approach of ignoring trade-offs results in unacceptable ecosystem, economic, or social effects. Overall, a "Pretty Good Yield" concept may be more suitable than trying to reach the absolute maximum of one particular objective.

Often decisions and compromises are needed that go beyond science when dealing with trade-offs and participants indicated that inclusive governance is of great importance. One important outcome of the management reflection workshops was the view that scientists should not make the decisions, but should only give advice on the range of potential options within a sustainable exploitation space. It is then up to the other stakeholder groups to make final decisions. In our approach, we tried to include different stakeholder groups from the start to enable discussions on difficult trade-offs and to provide options for sustainable exploitation. In the following sections the different aspects of lessons learned from this exercise are discussed in detail.

4.2 Uncertainties of model results and recommendations for visualisation

When providing advice for fisheries management, a major source of uncertainty is related to the scenario modelling. Different modelling approaches may not only change the apparent weight of trade-offs, but also the direction of change for a given key decision variable. Such problems are encountered regularly and diversified scientific approaches are encouraged, for instance with the growing use of ensemble modelling (Murphy et al. 2004, Thorpe et al. 2016). Often resources are not available to construct a variety of models for the same problem (as in our case here) and this can lead decision makers to wrongly assume that the advice they give is robust, whereas a more comprehensive modelling effort might have revealed the same advice as being contingent upon model assumptions and sensitive to a range of uncertainties. Visualisation techniques, such as icon arrays, can make comparisons among several sets of modelling results easier, but they can also contribute to a false sense of certainty. Thus the problem of subjectivity – presenting a single model outcome from a set of possible scientifically valid conclusions – can be made more acute by representing these results effectively and memorably using pictograms. Similarly, visualisation of expert preferences and uncertainties associated with those values as done in the stakeholder workshops is subject to linguistic uncertainty related to the lack of consistency of definitions such as 'good' or 'very poor' across stakeholders. Comparatively, the sensitivity to the parameterization of distributions representing opinions is a relatively minor issue (Holt et al 2014).

At the decision support workshop the uncertainties regarding the modelling approaches were clearly expressed during presentations and the comments from stakeholders during the discussions show that these uncertainties were recognized and taken seriously. Our predictions were sensitive to various assumptions. For example, assumptions on the future productivity of stocks may determine whether stocks are predicted to be above or below biomass reference points. Market prices for fish and fuel prices may also change in the future and therefore influence the profit of fleets. There are many other sources of uncertainty, e.g. food web dynamics or assumptions on future catchabilities under the landing obligation. In general, the famous quote "All models are wrong, but some are useful" (Box and Draper 1987) also holds true for the three case studies presented. Under this premise, it was not the aim to predict what will happen exactly in the future, but to highlight general trade-offs and to find out the preferences of stakeholders when confronted with such trade-offs based on the current situation. The model results only show likely conflicts which stakeholders need to consider. The management itself must be carried out in an adaptive way, based on the decisions on general objectives.

4.3 What are the main trade-offs?

According to our results, one main trade-off in setting long term management targets for an interacting fish community is the trade-off between maintaining a large stock of predators, which provide a large and valuable yield, versus reducing the predatory stocks to achieve a higher yield of prey fish. Similar results using different types of multi-species and ecosystem models have been obtained for a range of ecosystems (Gislason 1999; Matsuda and Abrahms 2004, 2006; Jacobsen et al. 2014, Thorpe et al. 2016) suggesting some generality of the result.

The main distinction between MEY and MSY objectives is that the MEY scenarios represent a maximisation of the profit from the fish stocks to society when the profit to the fishermen and the capital are embodied in the cost function, that the prices and costs are estimated as financial costs rather than opportunity costs (best alternative use) and that external effects such as positive or negative impact on the ecosystem are disregarded. In the MSY scenarios catch quantity or value is maximised but this will not lead to maximisation of the resource rent to society. However, as catch quantity and fishing effort is higher at the MSY level compared to the MEY level it is likely that employment in the fisheries sector is higher and that supplies of fish to processors and consumers are higher. This trade-off has also been discussed in other literature (e.g., Hilborn 2007, Christensen 2010, Sumaila and Hannesson 2010). Thus the question raised by the MEY vs. MSY dichotomy is what benefits society most in the long run, either that the fishery contributes most economically, i.e. with the highest catch value to the lowest costs, or that higher employment and higher food supply can be maintained. Before answering this question, alternative employment opportunities must be taken into account. For fisheries in remote communities, alternative opportunities for employment and development may be limited (Mardle et al. 2004).

The requirement for impacts on by-catch species to be sustainable can lead to additional trade-offs between the maximisation of yield from the target species and conservation targets. In the test case for the southern North Sea, the loss in profit as a result of preventing by-catch for the modelled species was only marginal, but catches that could be taken from target stocks and employment were substantially constrained. MEY is often considered to be more environmentally beneficial in terms of reduced bycatch and habitat damage due to lower fishing effort (Grafton et al. 2007; Dichmont et al. 2008). This conclusion is also supported by our modelling results.

So called “choke species” constrain mixed fisheries under a landing obligation due to an obligation, if strictly implemented, to close the fishery when their quotas are exhausted. Similar to our results for North Sea demersal fisheries, several “choke species” were identified in analyses of the Scientific, Technical and Economic Committee for Fisheries (STECF 2014) and the ICES working group WGMIXFISH (ICES WGMIXFISH 2014). Resolving the “choke species” problem is complicated in Europe because of the relative stability principle. This principle ensures that each year countries get the same quota shares based on historical fishing rights. In some countries even national quotas are distributed based on relative stability criteria. The traditional management scenario in the second DST (see Fig 4) mimics this approach by not allowing any redistribution of quota shares between fleets. The losses in yield and NPV were substantial in comparison to a system where at least redistributions inside a country were allowed. It can be deduced from these results that with a complete removal of the relative stability principle, allowing redistribution freely, even better economic results may be achieved, albeit possibly at the expense of greater inequality between countries and the fear that a few large companies will monopolize quotas. Currently a system of quota swapping is used to overcome the limitations caused by the principle of relative stability (Hoefnagel *et al.* 2015). However, it is unclear how such a system of voluntary quota exchanges will function under the landing obligation.

4.4 Resolving the trade-offs

What were the main priorities for stakeholders?

A key priority for stakeholders was that harvest strategies must be sustainable. In the problem framing workshop GES related constraints were ranked as most important. This is in line with the new CFP where the implementation of an ecosystem approach is an important objective. However, the achievement of GES could lead to additional constraints for North Sea fisheries.

In addition, participants of the different workshops considered a successful implementation of MSY to depend critically on viable fisheries, and MEY was ranked highest in the decision support workshops where possible. While social aspects played only a small role during the problem framing workshop, social aspects were also raised by stakeholders after confronted with the results from the DSTs. Often expressed was the desire to find a compromise between economic optimisation and social constraints (e.g., employment, food security). In other studies, Wattage et al. (2005) used a choice experiment, whereas Mardle et al. (2004) applied the analytical hierarchy process (AHP) to elicit stakeholder preferences in North Sea and Eastern Channel fisheries. Both approaches also demonstrated that maintaining regional employment and the sustainable exploitation of stocks were key concerns. Therefore, results in this study are similar despite differences in stakeholder groups and elicitation methods.

A suitable compromise could be the “Pretty Good Yield” concept that was also favoured from the DST on biological interactions. In mixed fisheries of the North Sea the individual MSYs/MEYs cannot be achieved for all species simultaneously because of biological and technical interactions (Mackinson et al. 2009). Sustainable ranges for F_{MSY} in accordance with the “Pretty Good Yield” concept are one option to minimize this problem. The aim would be to keep all stocks within their individual sustainable ranges leading to pretty good yield (e.g., at least 95% of the maximum) instead of trying to fish all stocks simultaneously at their stock specific F_{MSY} point estimate. This means a less strict interpretation of the MSY concept because ranges could also include sustainable fishing mortalities above F_{MSY}. But this gives room to find compromises and reduces the limiting effect of choke species under the landing obligation.

Inclusive governance

Inclusive governance was identified by stakeholders as most important in the problem framing workshop. Inclusive governance can be seen as an essential part of fisheries management because of the need for a balanced and stable outcome on all three dimensions of sustainability – ecological, economic and social (Rice 2011). The historic failure to include the major stakeholders in meaningful decision-making has long been seen as one of the causes of failures in fisheries management (Cochrane 1999) while increased stakeholder participation helps establish trust, resolves conflicts, enhances the legitimacy and acceptance of management policies and increases the likelihood of compliance (Jentoft and McCay 1995, Berghofer et al. 2008).

A challenge and strength of inclusive governance lies in the consideration of interests from different participants in the governance process (Rochet and Rice 2005). Scientists, fishing industry, policy-makers and NGOs often gave different weights to the different features of a decision (not shown in the results because of privacy protection). During the elicitations for this study all participants got an equal say. Although it was ensured that representatives from each stakeholder group (Industry, NGO's, Managers, Scientists) participated in the elicitation process, composition of workshop participants may have biased the results to some extent. It was the diversity of views that was most interesting for this study and therefore the different views are highlighted in the discussion and not only the most preferred ones. The main outcome of the stakeholder elicitation was that there is no simple solution satisfying the objectives of all stakeholders at the same time. Therefore, setting F_{MSY} or F_{MEY} as management target without any flexibility for compromises may lead to disappointment for some stakeholders. This conclusion is robust to any potential bias in the composition of workshop participants. A well-structured decision making process with clear responsibilities is therefore needed in fisheries management to resolve trade-offs and find compromises. This is an important point because inclusive governance alone may also lead to a management system that is blocked by too many conflicting views. The elicitation process carried out for this study can be used also in practice to deal with difficult trade-offs. However, a more targeted stakeholder screening may be needed before the start of the process and participants should not change in between the different steps. The final decision making is an additional task that was not in the scope of this scientific study.

Perspectives

The CFP (EU 2013) states that management decisions should take into account the difficulty of fishing all stocks in a mixed fishery at maximum sustainable yield at the same time and that multiannual plans should cover the interactions between fish stocks, fisheries, and marine ecosystems. The general principle of treating F_{MSY} not as a point estimate but to use sustainable ranges to find a compromise between the various objectives and trade-offs has been explicitly acknowledged by the European authorities (Task force 2014). ICES has been tasked with identifying these ranges for a number of stocks using a standardised framework (ICES WKMSYREF III 2014). These elements may be an important element of the regional mixed-fisheries management plans currently being developed. For the North Sea, STECF evaluated that F_{MSY} ranges could lead to more flexible sustainable management of mixed-fisheries, provided that TACs are not blindly set at the maximum of the range each year across all species in the fishery (STECF 2015). However, discussions are ongoing whether F_{MSY} ranges can be compatible with the basic regulation of the CFP (EU 2013) and the Marine Strategy Framework Directive (MSFD; EU MSFD 2008) or if single species point estimates of F_{MSY} should be considered an upper limit. The yield and profits from North Sea fisheries will depend on agreed reference levels and how GES indicators from the MSFD influence the CFP. A harmonised approach between the CFP and MSFD is a prerequisite for a successful implementation of the MSY concept inside an ecosystem-based approach. This study gives insights on how inclusive governance and appropriate elicitation tools can help in such difficult political processes to reach consensus and how science can be used to make informed decisions inside a multi-dimensional trade-off space. The results of this study also highlight problems that can be anticipated when implementing the MSY policy in the North Sea, suggesting that MSY is a useful concept but that a pragmatic adaptation may be needed to reconcile the diverse and often conflicting views regarding fisheries management in Europe.

5. Acknowledgement

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Figure captions

Figure 1. Composition of workshop participants in the 4 workshop events. Total number of participants are given in white at the bottom of each bar.

Figure 2. Graphical tool to record ratings. If the group rates (R) an aspect 'Very good (VG)' and the uncertainty (U) or disagreement is very low, the resulting distribution shows a high column in 'Very good (VG)' and a small column in 'Good (G)'. Keeping 'U' constant at 'Very low' while changing 'R' to 'Medium (M)' or 'Very poor (VP)' retains the narrow distribution but shifts the mode towards the right. In contrast, increasing 'U' to 'High' leads to a larger spread.

Figure 3. Decision support table showing three scenarios to investigate the effect of fish eating other fish on MSY: maximise the total landings in tonnes, maximise the total landings in Euros and an iterative process where it is attempted to get a yield in tonnes close to the maximum of each species while assuring that no species are exploited unsustainably (Pretty Good Yield). Catch is indicated by the number of fish of each species and the number in each cell. Colour indicates whether the average spawning stock biomass (SSB) of all species is above the precautionary biomass reference point Bpa (green), whether the SSB of at least one species is below Bpa but above Blim (yellow) or below Blim (red). Empty cells mean zero catch. Even a small catch leads to a stock collapse of whiting with high probability in the respective scenarios.

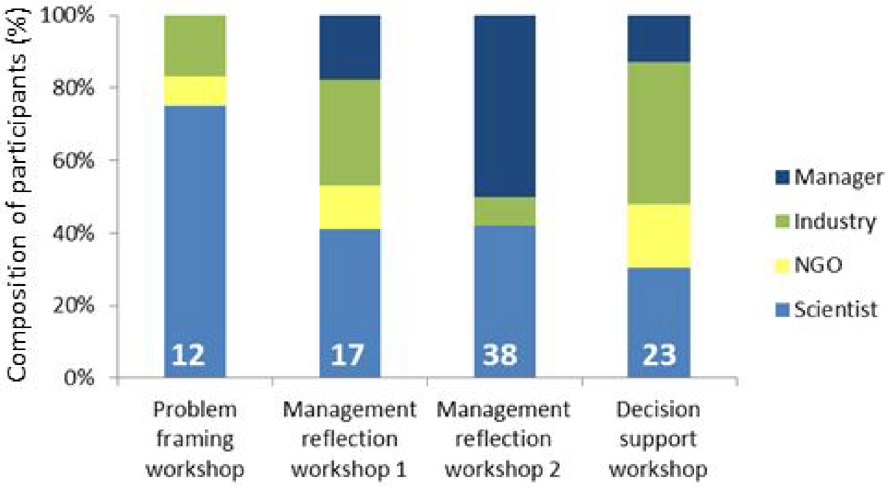
Figure 4: Decision support table on the comparison between traditional management (distribution of quotas determined by historic landings shares) and three optimisation scenarios in the mixed demersal roundfish fishery. Catch in thousand tonnes is indicated by the number of fish of each species. The net present value (NPV) in million Euros is indicated by the number of Euro signs. Employment in full time equivalents (fte) is indicated by the number of people. Effort in days at sea is

indicated by number of vessels. Yellow colour indicates spawning stock biomass (SSB) below $B_{pa.}$ but above $B_{lim.}$ Green colour indicates SSB above Bpa.

Figure 5: Decision Support Table (DST) on the consequences of aiming for different MSY/MEY objectives in the main fisheries of the southern North Sea. Catch in thousand tonnes is indicated by the number of fish of each species. The profit in million Euros is indicated by the number of Euro signs and negative profit is red. Employment in full time equivalents (fte) is indicated by the number of people. Effort in days at sea is indicated by number of vessels. Green colour indicates SSB above Bpa. For brown shrimp (*Crangon crangon*) no reference points are defined.

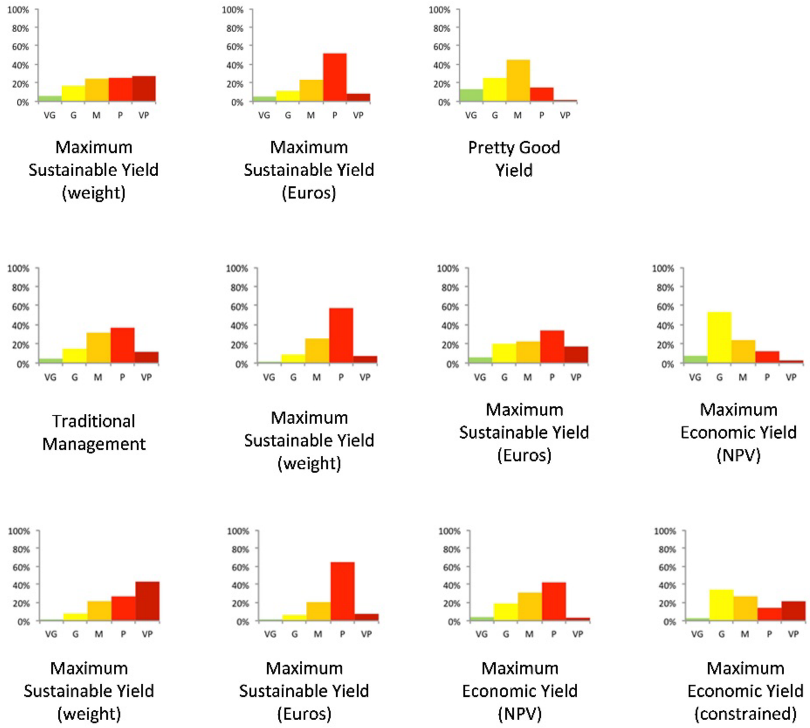
Figure 6: a) Consequences of aiming for different MSY/MEY objectives in the main fisheries of the southern North Sea for the sustainable exploitation of selected bycatch species. b) Impact on a modelled large fish indicator based on the percentage of biomass from demersal species with length infinity above 40 cm.

Figure 7: Stakeholder frequency of ratings on options given in the three DSTs. Top row: DST1 on biological interactions. Middle row: DST2 on traditional vs. MSY/MEY management. Bottom row: DST3 on MSY/MEY objectives in the southern part of the North Sea. VG=very good; G=good; M=Medium; P=poor; VP= very poor.



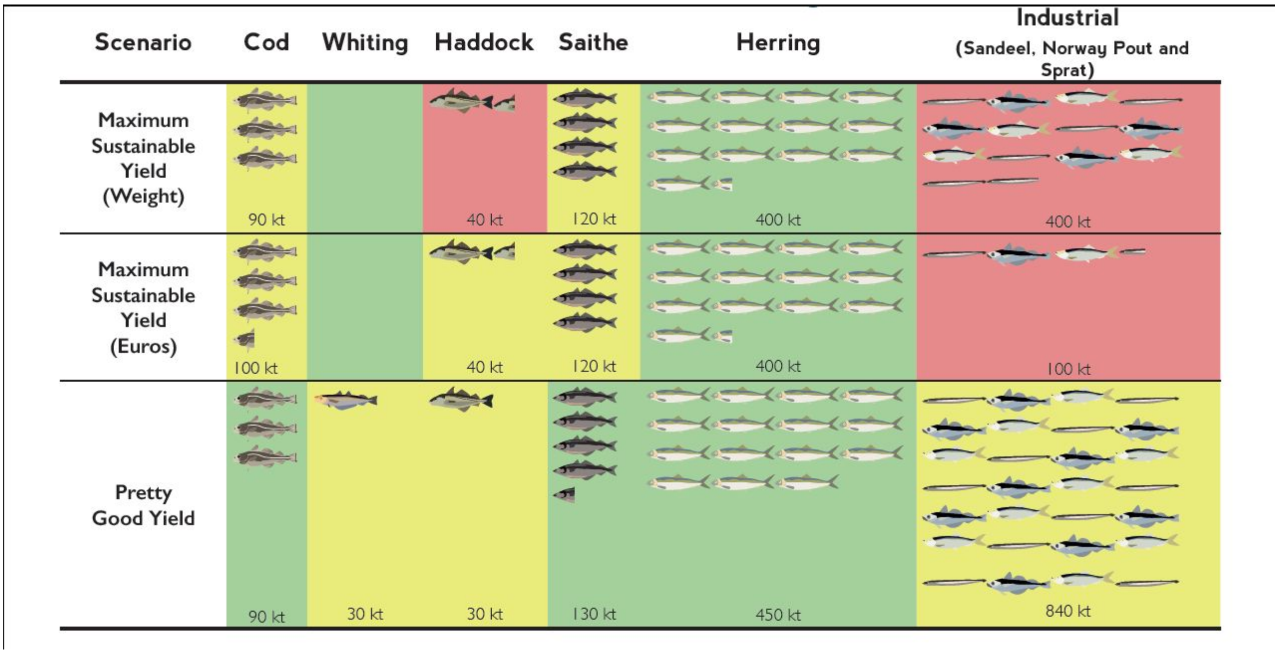
Composition of participants (%)
100%
80%
60%
40%
20%
0%
12
17
38
23
Problem framing workshop
Management reflection workshop 1
Management reflection workshop 2
Decision support workshop
Manager
Industry
NGO
Scientist

Fig-. 1



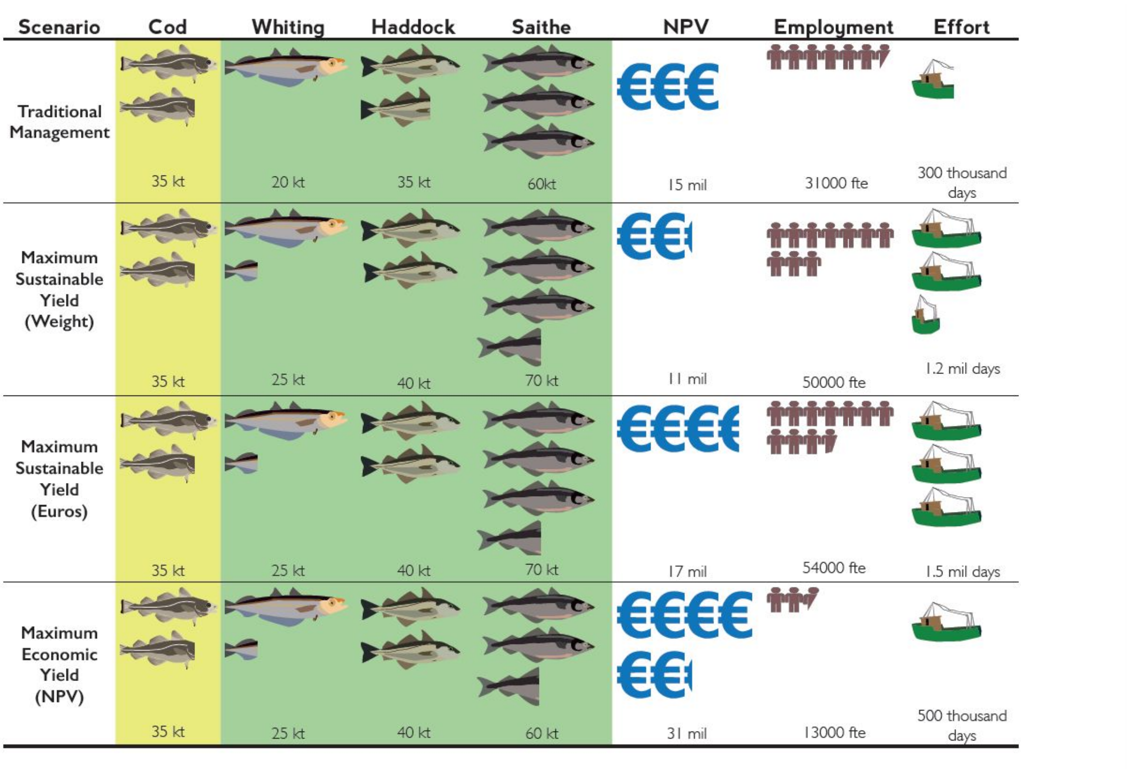
Maximum Sustainable Yield (weight)
Maximum Sustainable Yield (Euros)
Pretty Good Yield
Traditional Management
Maximum Sustainable Yield (weight)
Maximum Sustainable Yield (Euros)
Maximum Economic Yield (NPV)
Maximum Sustainable Yield (weight)
Maximum Sustainable Yield (Euros)
Maximum Economic Yield (NPV)
Maximum Economic Yield (constrained)

Fig. 2



Scenario
Cod
Whiting
Haddock
Saithe
Herring
Industrial
(Sandeel, Norway Pout and Sprat)
Maximum Sustainable Yield (Weight)
90 kt
40 kt
120 kt
400 kt
400 kt
Maximum Sustainable Yield (Euros)
100 kt
40 kt
120 kt
400 kt
100 kt
Pretty Good Yield
90 kt
30 kt
30 kt
130 kt
450 kt
840 kt

Fig. 3



Scenario
Cod
Whiting
Haddock
Saithe
NPV
Employment
Effort
Traditional Management
35 kt
20 kt
35 kt
60kt
15 mil
31000 fte
300 thousand days
Maximum Sustainable Yield (Weight)
35 kt
25 kt
40 kt
70 kt
11 mil
50000 fte
1.2 mil days
Maximum Sustainable Yield (Euros)
35 kt
25 kt
40 kt
70 kt
17 mil
54000 fte
1.5 mil days
Maximum Economic Yield (NPV)
35 kt
25 kt
40 kt
60 kt
31 mil
13000 fte
500 thousand days

Fig. 4

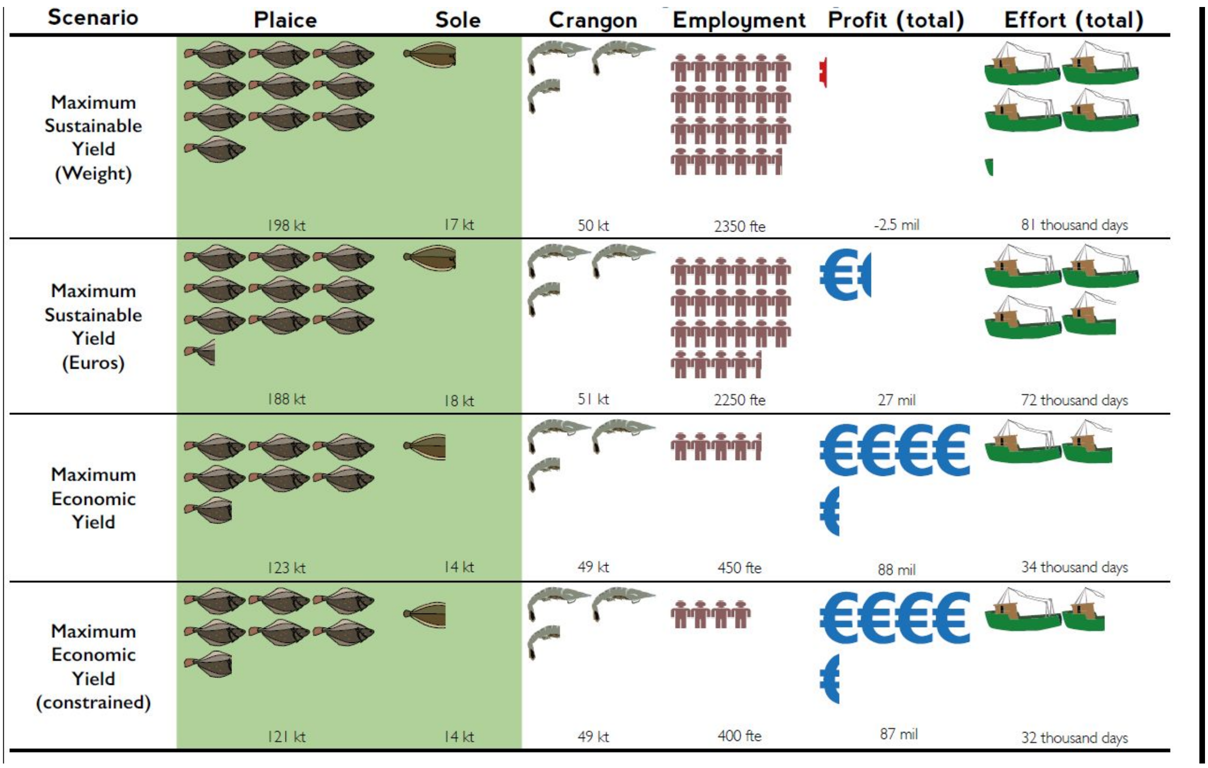

Scenario
Plaice
Sole
Crangon
Employment
Profit (total)
Effort (total)
Maximum Sustainable Yield (Weight)
198 kt
17 kt
50 kt
2350 fte
-2.5 mil
81 thousand days
Maximum Sustainable Yield (Euros)
188 kt
18 kt
51 kt
2250 fte
27 mil
72 thousand days
Maximum Economic Yield
123 kt
14 kt
49 kt
450 fte
88 mil
34 thousand days
Maximum Economic Yield (constrained)
121 kt
14 kt
49 kt
400 fte
87 mil
32 thousand days

Fig. 5

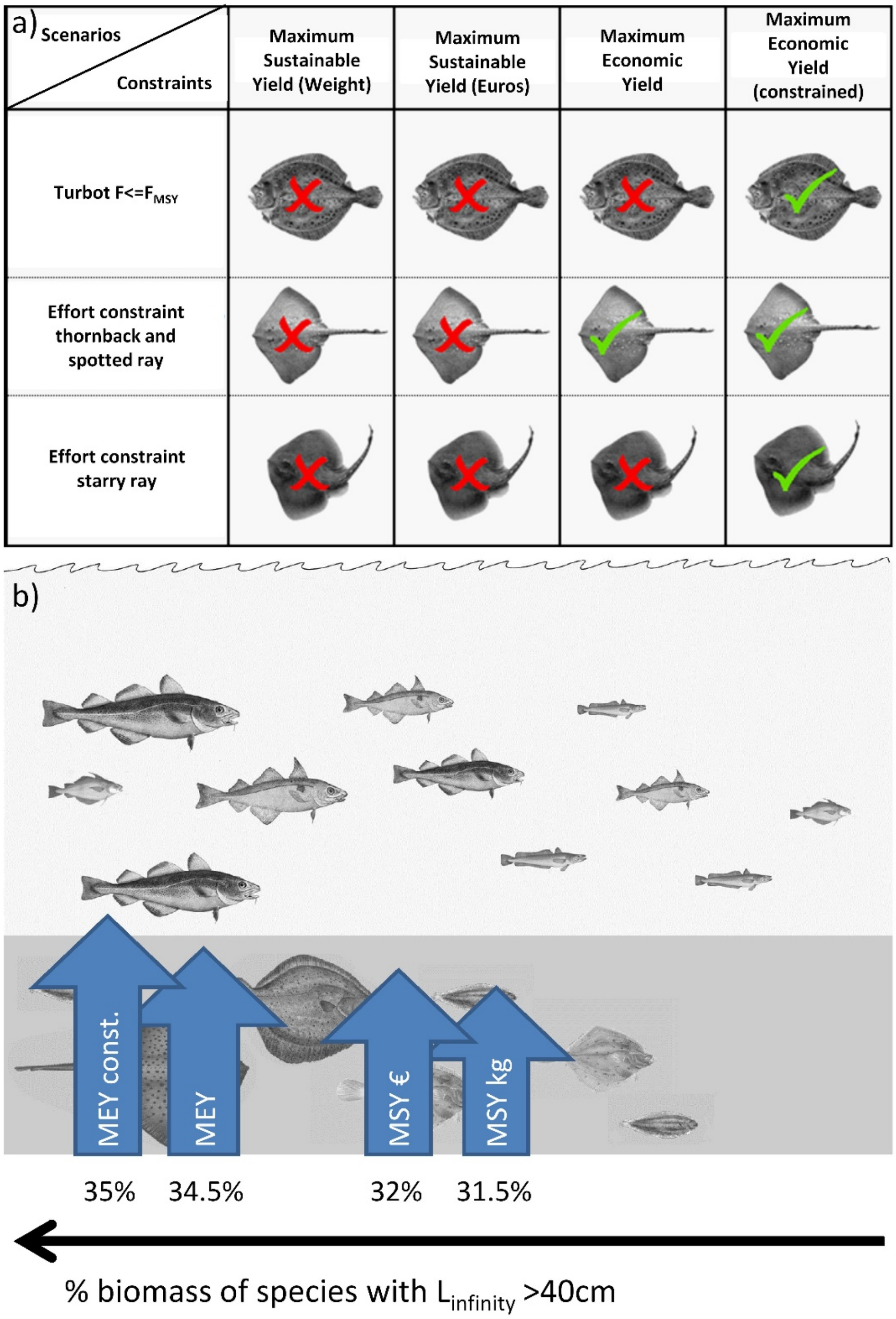
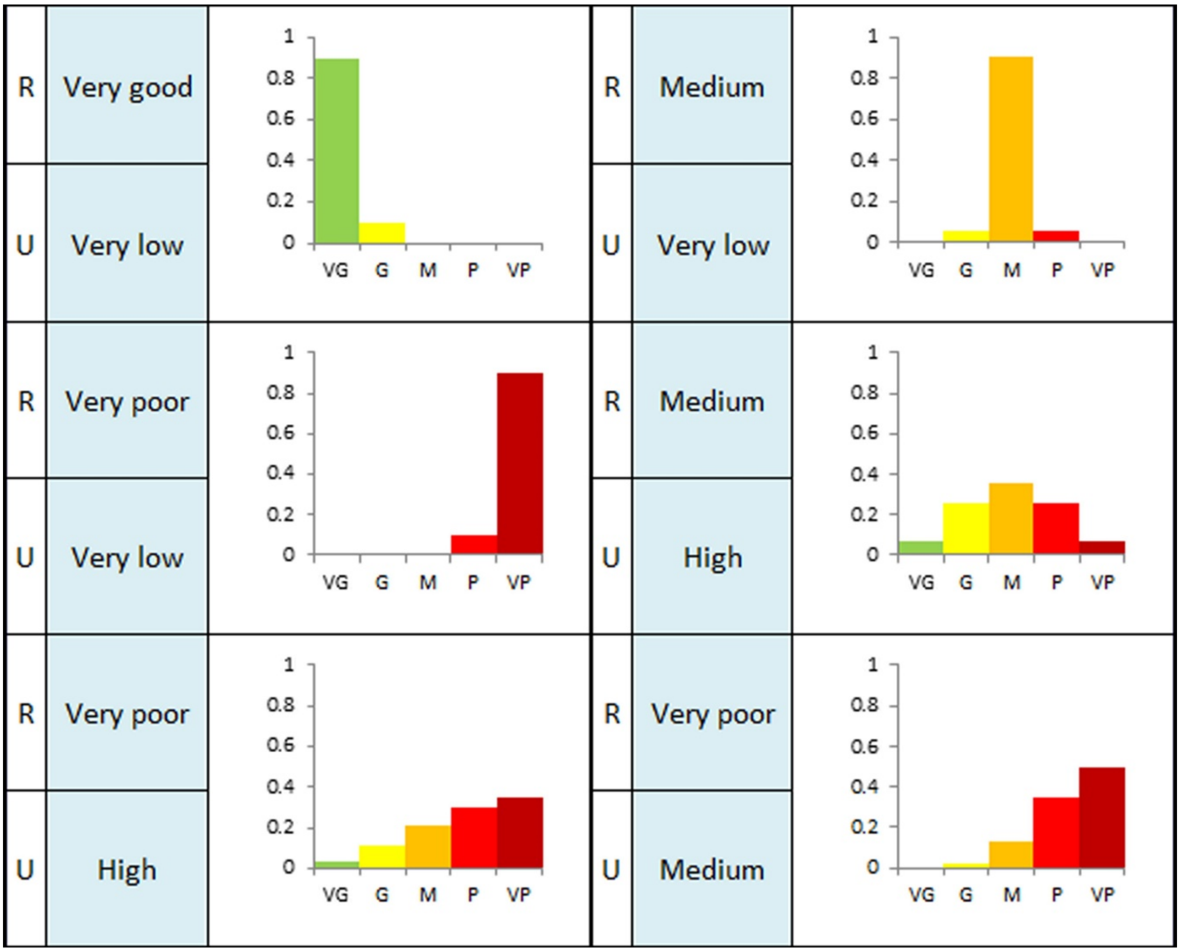

a)
Scenarios
Constraints
Maximum Sustainable Yield (Weight)
Maximum Sustainable Yield (Euros)
Maximum Economic Yield
Maximum Economic Yield (constrained)
Turbot F<=F$_{MSY}$
Effort constraint thornback and spotted ray
Effort constraint starry ray
b)
MEY const.
MEY
MSY €
MSY kg
35%
34.5%
32%
31.5%
% biomass of species with L$_{infinity}$ >40cm

Fig. 6



R
Very good
U
Very low
R
Medium
U
Very low
R
Very poor
U
Very low
R
Medium
U
High
R
Very poor
U
High
R
Very poor
U
Medium
1
0.8
0.6
0.4
0.2
0
VG
G
M
P
VP

Fig. 7

Table 1. Ranking of MSY objectives by participants of the problem framing workshop. Lower utility values correspond to preferred options.

Priority	MSY objectives	Expected utility
1	Maximise inclusive governance	0.46
	Maximise yield of fish/litre of fuel (or CO2) or similar energy unit	0.47
	Maximise yield in value of key commercial species	0.53
	Maximise consumer welfare/happiness	0.62
	Maximise yield in value	0.77
	Maximise yield in tonnes of key commercial species	0.77
	Maximise stability	0.78
2	Maximise Net Present Value	0.82
	Maximise Gross Value Added	1.14
	Maximise fisher welfare/happiness	1.52
	Maximise Gross Value Added over the entire value chain	1.57
3	Maximise yield in tonnes	1.66
	Maximise useful knowledge	1.78
	Maximise Social Yield	1.80
	Maximise willingness to invest in the future fisheries	1.87
	Maximise fishing community viability	1.93
	Maximise resilience	2.22
4	Maximise stability of stocks	2.41
	Maximise Resource Rent	3.12

Table 2. Ranking of constraints by participants of the problem framing workshop. Lower utility values correspond to preferred options.

Priority	Constraint	Expected utility
1	GES descriptors of commercial species above reference level	0.10
	GES descriptors of biodiversity above reference level	0.10
	GES descriptor of food web functioning above reference level	0.10
	GES descriptors of seafloor integrity above reference level	0.10
	Areas with fishing restrictions (e.g., Natura 2000)	0.10
	Mortality of PET and other vulnerable species below specified level	0.10
	Discard of non-target species below specified level	0.10
	Legislation adhered to/compliance	0.10
	Maintain relative stability	0.10
	Human accidents at sea below a specified level	0.10
	Maintain trust among industry participants	0.67
2	Profits above a minimum level	1.04
	Carbon footprint less than specified level	1.06
	Maintain trust among all stakeholders	1.06
	Equity of income	1.06
	Increase level of self-determination for fishing actions by fishers	1.06
	Maintain fishing rights and ownership	1.21
3	Stability of landings	2.00
	Retain subsidies	2.00
	Maintain small communities at specified level	2.00
	Maintain vessel size distribution at a certain level	2.00
	Maintain consumer choice for different kinds and sources of fish	2.00
4	Maintain human food supply above specified level	2.96
5	Management costs below specified level of Gross Values Added	3.90
	Technical selectivity unaltered	3.90
	Employment above a specified level	3.90
	Increase status of fishers	3.90
	Reduce barriers to mobility in the fishing industry (to join or leave)	3.90